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MANUFACTURING METHOD OF DETECTION PROBE FOR VERY SMALL DISPLACEMENT,
DETECTION PROBE FOR VERY SMALL DISPLACEMENT, SCANNING PROBE MICROSCOPE
AND DATA PROCESSOR USING THESE

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[Claim 1] A manufacturing method of a detection probe for very small displacement having a probe point at the free end of a cantilever, for detecting the cantilever's very small displacement being generated by interaction of the probe point and a sample by an optical method using measuring light, comprising steps of:

- (1) forming a buffer layer on a transparent layer against the measuring light, the buffer layer being removed at post-process;
- (2) forming a cantilever support on the transparent layer;
- (3) forming a cantilever main unit on the buffer layer; and
- (4) removing the buffer layer after the cantilever is formed.

[Claim 2] A detection probe for very small displacement manufactured by the method as set forth in Claim 1, wherein the cantilever is formed on the transparent layer having a reflection surface on its one side for partially reflecting the measuring light with keeping void space against the transparent layer.

[Claim 3] The detection probe for very small displacement as set forth in Claim 2, wherein a reflection surface is formed on the surface being opposed to the transparent layer of the cantilever.

[Claim 4] The detection probe for very small displacement as set forth in Claim 2 and Claim 3, wherein the void space between the transparent layer and the cantilever is shorter than the wavelength of the measuring light.

* Claim and paragraph numbers correspond to those in the foreign text.

[Claim 5] The detection probe for very small displacement as set forth in Claim 2 through Claim 4, wherein the probe point mounted at the free end of the cantilever is made up of conducting material, and is equipped with an electrode to apply tunnel current between the probe point and the sample.

[Claim 6] A multi detection probe for very small displacement having a plurality of the detection probes for very small displacement as set forth in Claim 2 through Claim 5 on a single substrate.

[Claim 7] A scanning probe microscope operable by neighbor interaction between a probe and a sample, wherein the detection probe for very small displacement as set forth in Claim 2 through Claim 6 is employed for the probe.

[Claim 8] A data processor for recording and reproducing data to a recording medium through a probe, wherein the detection probe for very small displacement described in Claim 2 through Claim 6 is employed for the probe.

[Detailed Description of the Invention]

[0001] [Field of Invention]

The present invention relates to a detection probe for very small displacement which is used for detecting atomic force or tunnel current, and to a scanning probe microscope as well as a data processor which employ this detection probe.

[0002][Prior Art]

As a surface observation method with high resolution performance of real space regardless of mono crystal or amorphous, devices which are generally named a scanning probe microscope (hereinafter called SPM) have been developed for the purpose of measuring various forces generated by neighbor interaction of a sample and a probe. A scanning tunneling microscope (STM) (G. Binning et al. Phys. Rev. Lett. 49, 57 (1982)) , which has been getting attention in recent years, is a device to examine a surface state using tunnel current and field emission current which are obtained when a probe and a sample are approached to each other. Also, a scanning atomic force microscope (AMF) is a device to examine a sample's surface state by detecting atomic force generated when the sample and a probe are approached to each other.

[0003] As the probe, a probe which is equipped with a probe point on a cantilever is known. Conventionally, there is a SPM that measures the displacement of a cantilever by an optical interferometer, more particularly by Fabry-Perot resonator, which is filed by (a) G. Binning (EP0290648, JP63-309802). The configuration of this invention is described in Figure 11 [sic: translator's note - there is no Figure 11]. This invention describes a configuration of a Fabry-Perot resonator by a reflection mirror 73 which is arranged on a cantilever 5, a half mirror 74 which is arranged at the opposite surface of a support 71, and a via hole 72 which is arranged at the support 71.

[0004] Also, as another existing example, there is (b) Rev. Sci. Instrum., Vol. 62, No.5, p.p. 1280-1284 (1991) reported by the P. Mulhern team and its configuration is described in Figure 12 [sic: translator's note - there is no Figure 12]. This invention describes a configuration of a Fabry-Perot resonator using a jig 82 with high precision to make an end of an optical fiber 84 one of reflection surfaces.

[0005] [Problems that the Invention is to Solve]

However, with the aforementioned existing example (a), the space between reflection surfaces 73 and 74 that configures the Fabry-Perot resonator becomes farther apart than the thickness of a probe support 71. It is impossible to make the probe support thickness the wavelength of the measuring light or shorter, in terms of handling as well as manufacturing technology. Therefore the following problems exist: (1) if attempting to narrow down the measuring light to the wavelength or about 10 times of the wavelength results in poor light parallelism which leads dark interference fringe or which decreases contrast due to the extension of the beam traveling back and forth the resonator, (2) on the contrary, if a thick beam with good parallelism is used, displacement of the cantilever differs from the free end side and the fixed end side, thus the movement of the interference fringe obtained becomes complicated, or the contrast is decreased.

[0006] Also, with the existing example (b), a worker's high proficiency in adjustment or a jig with high precision is required in order to approach each of the resonator's two reflection surfaces, the

reflection surface which is at the end of the optical fiber and the reflection surface which is on the cantilever 8, as well as to make them almost parallel. Also the productivity of this example is low.

[0007] Therefore, the present invention is to provide a probe which is equipped with a Fabry-Perot resonator with its ability to obtain bright with high contrast interference fringe.

[0008] Another purpose of the present invention is to provide a scanning probe microscope [sic] and a data processor which are equipped with the aforesaid probe.

[0009] [Means for Solving Problems and Operation of the Invention]

The present invention made to accomplish the aforementioned purposes relates to a manufacturing method of a detection probe for very small displacement which, firstly, has a probe point at the free end side of a cantilever that detects a very small displacement of the cantilever generated by interaction of the probe point and a sample surface, by an optical method using measuring light. The manufacturing method of the detection probe for very small displacement includes the steps of (1) forming a buffer layer on a transparent layer against the measuring light which is removed at post-process, (2) forming a cantilever support on the aforesaid transparent layer, (3) forming a cantilever main unit on the aforesaid buffer layer, and (4) removing the aforesaid buffer layer after the cantilever is formed. Secondly, the present invention relates to a detection probe for very small displacement manufactured by the aforesaid first manufacturing method, having the cantilever which is formed on the

transparent layer whose one side has the reflection surface that partially reflects the measuring light, with keeping void space against the transparent layer. Thirdly, the present invention relates to a scanning probe microscope that operates with neighbor interaction between the probe and the sample using the aforementioned second detection probe for very small displacement for its probe. Fourthly, the present invention relates to a data processor to record and reproduce data on a recording medium through the probe for which the aforementioned second detection probe for very small displacement is used.

[0010] The detection probe for very small displacement of the present invention can be manufactured by general semi-conductor process technology and its illustrative embodiment is explained with reference to process diagrams shown in Figure 1.

[0011] At first, the first reflection layer 2 with its thickness at 100\AA to a few hundred \AA and with 50 to 90% of the measuring light reflectivity is formed on a substrate 1 (as illustrated in Figure 1 (a)). The substrate 1 holds a cantilever and a Fabry-Perot resonator, and a glass substrate can be used for the substrate if the measuring light (wavelength λ) is visible light, as well as a material which is transparent against the measuring light such as a glass or Si substrate can be employed if the measuring light is infrared light. As the first reflection layer 2, a vapor-deposited film or a dielectric multilayer such as Au or Cr can be used.

[0012] Next, a buffer layer 3 which is made up of Al or Ti with its thickness at about a few percent of λ is formed, and a part of the buffer layer 3 that becomes the cantilever support 3a is removed by etching using the photolithographic technique (as illustrated in Figure 1 (b)).

[0013] Next, the second reflection layer 4 is formed in the same manner as the first reflection layer 2 (as illustrated in Figure 1 (c)). This second reflection layer 4 is not necessarily required if the cantilever main unit which will be described later comprises a material which reflects the measuring light.

[0014] Next, a SiO_2 layer or a Si_3N_4 layer with its thickness at 0.5 to 1 μm which become the cantilever main unit 5 is formed by sputtering or by CVD. Furthermore, it is processed to the cantilever shape by the photolithographic technique, and a probe point 6 is formed thereon with Pt or the like by EB deposition (as illustrated in Figure 1 (d)).

[0015] Lastly, the buffer layer 3 which comprises Al or Ti is selectively removed by etching with a mix acid of hydrofluoric acid and nitric acid, for example (as illustrated in Figure 1 (e)). 7a indicates the measuring light, 7b indicates reflection light from the first reflection layer 2, and 7c indicates reflection light from the second reflection layer 4.

[0016] With regard to the detection probe for very small displacement of the present invention manufactured in such ways, the space between the reflection layer 2 arranged at the substrate 1 that becomes the transparent layer and the reflection layer 4 arranged at the cantilever 5 can be set

to the wavelength of the measuring light or shorter, as well as these reflection layers can be formed almost parallel. Therefore, it becomes the detection probe for very small displacement which enables it to obtain bright interference fringe with high contrast and which is equipped with the Fabry-Perot resonator.

[0017] The detection probe for very small displacement of the present invention is not restricted to the configuration shown in Figure 1 (e), and it also can be configured as described in Figure 2 or Figure 3.

[0018] With the configuration described in Figure 2, after forming a transparent layer 9 on a substrate 8, which is opaque, against the measuring light, a reflection layer 2, a reflection layer 4, a buffer layer 3, a cantilever 5, and a point 6 is formed in the same manner as Figure 1, and a part of the substrate 8 which transmits the measurement light 7a is removed.

[0019] With the configuration described in Figure 3, a reflection layer 2 is formed on a substrate 8 which is opaque against the measuring light in advance, and a transparent layer 9 is formed thereon, and then it is manufactured in the same manner as it is shown in Figure 2. The transparent layer 9 and void space 3b exist between the reflection layer 2 and the reflection layer 4.

[0020] If the cantilever main unit of the probe for very small displacement of the present invention is formed with insulating material, as illustrated in Figure 4, an electrode 10 is formed before forming the point 6 on the cantilever 5, using a material that does not get damaged

at the later buffer layer removal process such as Au, and the point 6 is formed with a conducting material such as Pt. In such ways, the probe which is equipped with the electrode 10 between the sample and the point 6 for applying tunnel current and with the Fabry-Perot resonator can be obtained

[0021] Although the cantilever support 5a and the cantilever main unit 5 are formed by the same material in the aforementioned configuration example, it is also possible to make the space of the two reflection surfaces adjustable by forming the support 5a with another material such as a piezoelectric body ZnO which is sandwiched with an Au electrode using vapor-deposition or sputtering, and by transforming the piezoelectric body with applying voltage thereto from outside.

[0022] [Embodiments]

Hereafter, embodiments of the present invention will be explained.

[0023] Embodiment 1

A probe for very small displacement as illustrated in Figure 1 is formed for this embodiment.

[0024] At first, an Au layer 2 with its thickness at 300 Å and with 50% of measuring light reflectivity (wavelength is 6328 Å) is vapor-deposited on a glass substrate 1 (Figure 1 (a)). Further, an Al buffer layer 3 with its thickness at 2000 Å is vapor-deposited thereon, and the part that becomes a cantilever support 3a is removed by etching using the photolithographic technique (Figure 1 (b)). Furthermore, a reflection layer 4 which is the same material as the reflection layer 2

is vapor-deposited (Figure 1 (c)). On the reflection layer 4, a SiO_2 layer which becomes a cantilever main unit 5 with its thickness at $0.5\mu\text{m}$ is formed by sputtering or by CVD. The SiO_2 layer is further processed to cantilever shape by the photolithographic technique, as well as a point 6 is formed thereon by EB deposition using Pt (Figure 1 (d)). After that, the Al buffer layer 3 is selectively removed by etching using mixed acid of hydrofluoric acid and nitric acid (Figure 1 (e)).

[0025] The probe for very small displacement manufactured in this embodiment has two reflection surfaces which are positioned almost parallel with 2000\AA of the space in between as well as they are formed shorter than the wavelength of the aforesaid measuring light, thus interference fringe obtained through the use of the measuring light is very bright with high contrast.

[0026] Embodiment 2

A probe for very small displacement illustrated in Figure 2 is formed in this embodiment.

[0027] At first, a thermally-oxidized layer 9 is formed on the surface of a Si substrate 8 with opaque orientation (100) against visible measuring light. After forming a reflection layer 2, a reflection layer 4, a buffer layer 3, a cantilever 5 and a point 6 on the thermally-oxidized layer 9 in the same manner as Embodiment 1, the buffer layer 3 is removed, and furthermore, a part of the Si substrate which transmits the measuring light 7a is removed by anisotropic etching using KOH etchant.

[0028] With the probe for very small displacement of this embodiment as well, the interference fringe obtained through the use of visible light is very bright with high contrast.

[0029] Embodiment 3

A probe for very small displacement as illustrated in Figure 3 is formed in this embodiment.

[0030] At first, an Au reflection layer 2 is vapor-deposited on a Si substrate 8 with opaque orientation (100) against visible measuring light, as well as a SiO₂ transparent layer 9 is formed thereon by CVD. After forming a reflection layer 2, a reflection layer 4, a buffer layer 3, a cantilever 5 and a point 6 on the SiO₂ transparent layer 9 in the same manner as Embodiment 1, the buffer layer 3 is removed and a part of the Si substrate which transmits the measuring light 7a is removed by anisotropic etching using KOH etchant.

[0031] With the probe for very small displacement of this embodiment as well, the interference fringe obtained through the use of visible light is very bright with high contrast.

[0032] Embodiment 4

In this embodiment, sample surfaces are observed by placing the probes of the present invention which are manufactured in the embodiment 1 through 3 on a scanning probe microscope which is configured as shown in Figure 5.

[0033] At first, on the device illustrated in Figure 5, the position of an observation sample 55 is adjusted in order for the sample 55 to

approach less than 1nm of the distance from a probe point 6 by an X · Y · Z stage. Measuring light 7a which is output from light source 51 is reflected in the probe direction by a polarizing beam splitter 52, and the polarizing direction is rotated 45 degrees by a quarter wavelength plate 53. A part of the measuring light becomes reflection light 7b by the first reflection layer 2, and a part or all of the transmitted light becomes reflection light 7c by the second reflection layer 4. When the reflection light 7b and 7c transmit the quarter wavelength plate 53, the polarizing direction is further rotated 45 degrees, and the reflection light 7b and 7c is received by light receiving element 54 by transmitting the polarizing beam splitter 52. Light intensity received is resulted from the intensity of the multiple interfered reflection light. This light intensity is varied by the distance between the reflection layer 2 and the reflection 4, in other word, by the cantilever 5's deflection amount.

[0034] Through the use of this change in light intensity as the Z direction displacement signal, scanning in the X direction and in the Y direction are performed by an X, Y stage driving circuit 57, with adjusting the Z direction stage by Z direction feedback processing circuit 57 to fix the deflection amount of cantilever 5 which is generated by the interaction of the probe point 6 and the sample 55. At this point, it is possible to observe the surface state of the sample with a display device 58 by using the Z direction feedback signal which varies by the surface state of the sample 55 and the X, Y position signal.

[0035] A high precision scanning probe microscope is easily realized by employing the aforesaid probe.

[0036] Since we employ data recorded media as the observation sample 55, namely a surface-modulated HOPG (Highly Oriented Pyrolytic Graphite) cleaved surface, a Si wafer, Rh25Zr75, Co55Tb65, or a glassy metal, and by using the display device 26 as a data extraction device, a data reproduction device is also realized.

[0037] Embodiment 5

In this embodiment, a multi detection probe for very small displacement that includes a plurality of the probes for very small displacement which are manufactured on a single silicon substrate based on the manufacturing method of the probe for very small displacement in Embodiment 1 through 3 is mounted on a data processor configured as illustrated in Figure 6 by expanding the photolithograph pattern, and data recording and reproduction is performed.

[0038] For recording, pulsed voltage is applied to the randomly selected probe's electrode by a voltage imposer for recording 62. By the tunnel current applied between the probe's point 6 and a medium 55 (squarylium-bis-6-octylazulene, for example), data is recorded by changing the medium's surface state.

[0039] 61 is a light output unit which comprises a light source and a plurality of partial reflection mirrors. Light 7a which is output from the light output unit 61 becomes reflection light 7b and 7c by the two reflection surfaces in the same manner as in Embodiment 4. Light intensity

of the interference fringe generated by this reflection light is detected by a light receiving element array 63. The recorded data is successfully reproduced from the light intensity data obtained.

[0040] This probe enables the obtaining of bright interference fringe with high contrast, thus the data processor is realized with the simple light source structure without having a light source for each probe or switching the light path with a plurality of light switches.

[0041] [Effect of the Invention]

As described above, the present invention produces the following effects.

[0042] (1) It is possible to easily manufacture a detection probe for very small displacement whose two reflection surfaces are almost parallel, and the space between the two reflection surfaces is shorter than the wavelength of measuring light, with a Fabry-Perot resonator, by using general semi-conductor process technology.

[0043] (2) The interference fringe obtained by the probe of the present invention through the use of measuring light is very bright with high contrast so that it is possible to detect very small displacements more accurately and more precisely.

[0044] (3) A scanning probe microscope and a data processor which are structured by using the probe of the present invention become more accurate.

[Brief Description of the Drawings]

[Figure 1] Figure 1 is a cross-sectional view of an embodiment for a probe manufacturing process of the present invention.

[Figure 2] Figure 2 is a cross-sectional view of a probe for another embodiment of the present invention.

[Figure 3] Figure 3 is a cross-sectional view of a probe for another embodiment of the present invention.

[Figure 4] Figure 4 is a cross-sectional view of a probe for another embodiment of the present invention.

[Figure 5] Figure 5 is a schematic view of a scanning probe microscope using the probe of the present invention.

[Figure 6] Figure 6 is a schematic view of a data processor using the probe of the present invention.

[Figure 7] Figure 7 is a diagram describing a probe which is equipped with the existing example, a Fabry-Perot resonator.

[Figure 8] Figure 8 is a diagram describing a probe which is equipped with the existing example, a Fabry-Perot resonator.

[Description of the reference numerals]

- 1: substrate which is transparent against measuring light
- 2: the first reflection surface
- 3: buffer layer
- 3a: buffer layer which is removed to make the cantilever support
- 3b: void space created by removing the buffer layer
- 4: The second reflection surface
- 5: cantilever
- 6: probe point
- 7: measuring light
- 7a: incoming light [sic: translator's note - 7a is "measuring light" in the description above.]
- 7b: reflection light from the first reflection layer
- 7c: reflection light from the second reflection layer
- 8: opaque substrate
- 9: transparent layer
- 10: electrode
- 51: laser light source
- 52: polarizing beam splitter
- 53: quarter wavelength plate
- 54: light receiving element
- 55: observation sample or data recording medium
- 56: XYZ direction movement stage
- 57: Z direction feedback processing circuit and XY stage driving circuit

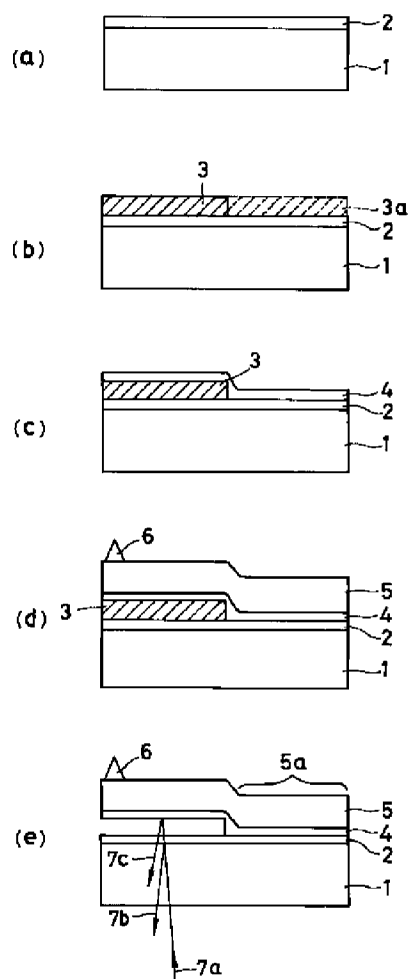
58: display device

61: light emitting unit comprising light source and an optical branching filter

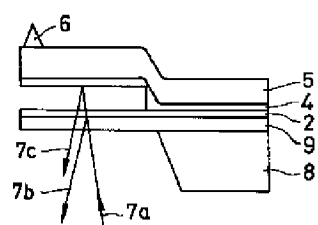
62: voltage imposer for recording

63: light receiving element array

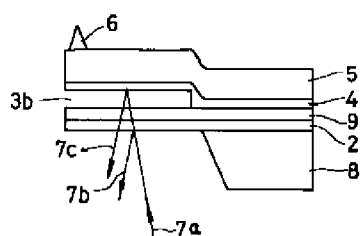
[Figure 1]



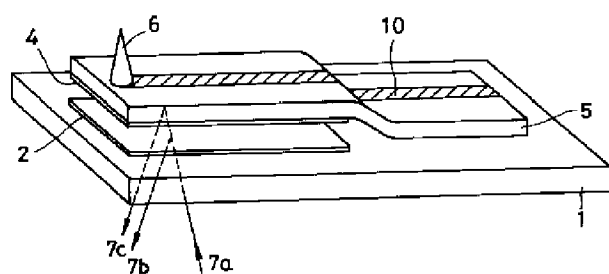
[Figure 2]



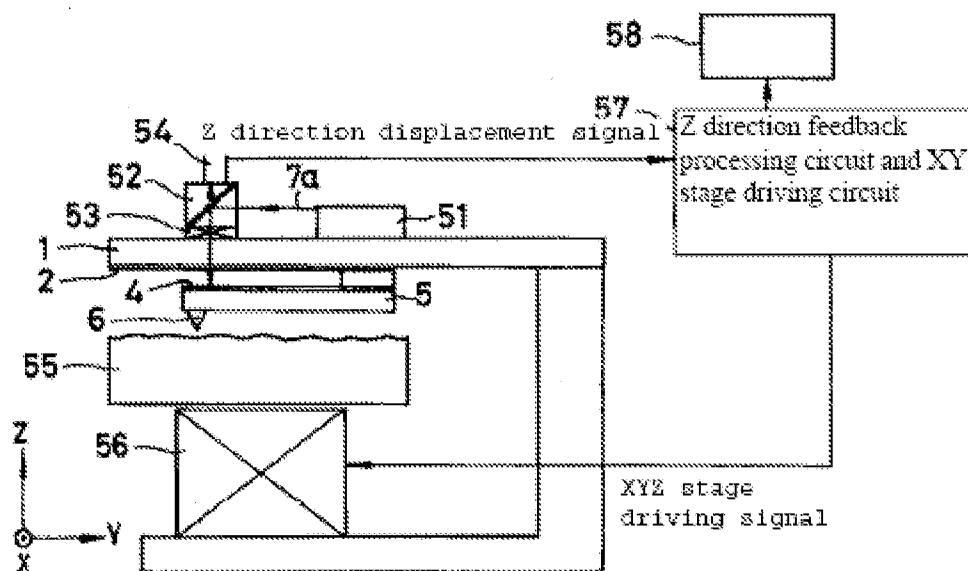
[Figure 3]



[Figure 4]

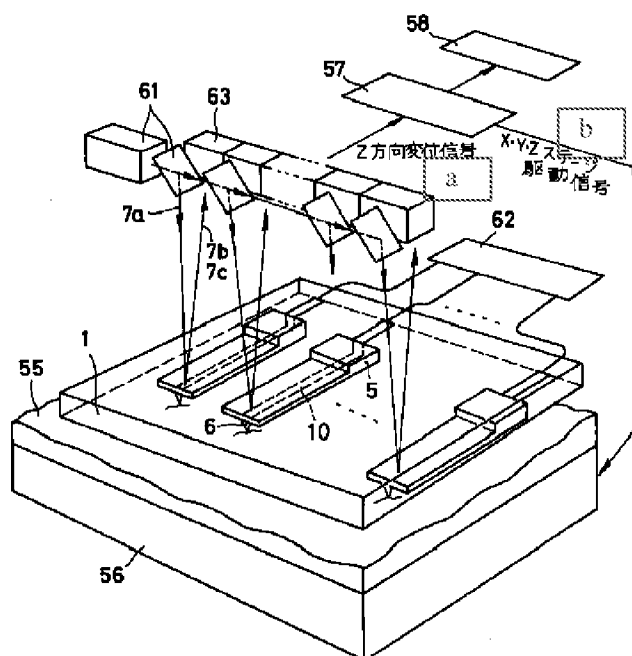


[Figure 5]



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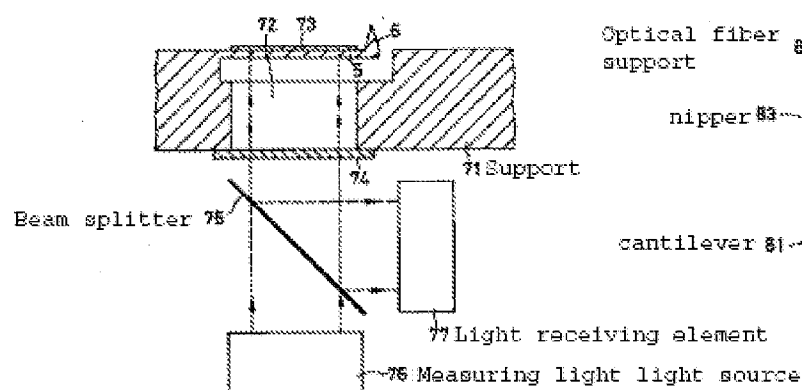
[Figure 6]



a): Z direction displacement signal
b): XYZ stage driving signal

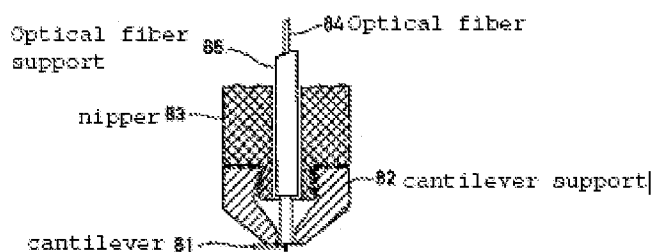
[Figure 7]

【図7】



[Figure 8]

【図8】



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